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Original Article

Sleep efficiency (but not sleep duration) of healthy school-age children is associated with grades in math and languages

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ABSTRACT

Objective: The objective of this study was to examine the associations between objective measures of sleep duration and sleep efficiency with the grades obtained by healthy typically developing children in math, language, science, and art while controlling for the potential confounding effects of socioeconomic status (SES), age, and gender.
Study design: We studied healthy typically developing children between 7 and 11 years of age. Sleep was assessed for five week nights using actigraphy, and parents provided their child's most recent report card.
Results: Higher sleep efficiency (but not sleep duration) was associated with better grades in math, English language, and French as a second language, above and beyond the contributions of age, gender, and SES.
Conclusion: Sleep efficiency, but not sleep duration, is associated with academic performance as measured by report-card grades in typically developing school-aged children. The integration of strategies to improve sleep efficiency might represent a successful approach for improving children's readiness and/or performance in math and languages.

1. Introduction

Low academic achievement in children is a common and serious problem that affects 10–20% of the population [1,2]. School outcomes largely determine long-term social and economic success, and a successful start to formal learning in school is formative to these outcomes [3]. Short or poor sleep is a significant risk factor for poor academic performance that is frequently ignored. Cognitive processes that underlie academic performance include executive functions [4–7], memory [8], and attention [9,10]. Sufficient and efficient sleep is essential for and intimately related to the optimal functioning of each of these processes [11,12]. On the other hand, poor or insufficient sleep can disrupt them and is associated with poor academic performance [13–15]. It is therefore critical that we investigate the association between sleep and the academic performance of children.

A considerable proportion of elementary school-aged children get less sleep than is recommended [16,17]. In a large survey, 34% of toddlers, 32% of preschoolers, and 27% of school-aged children were reported to sleep fewer hours than what their parents/caregivers thought they needed [18]. Objective evidence confirms these concerns, as a recent study using wrist actigraphy showed that children aged 4–10 years slept an average of 8 h per night, even though the recommended sleep duration for this age range is 10 h per night [19]. However, the amount of sleep needed remains an individual matter, and is difficult to determine precisely. In addition, studies using objective measures of sleep have revealed that even the normative population of typically developing children experiences a high prevalence of approximately two night wakings per night on average [20]. This is a major concern given that restricted and disrupted sleep can seriously impair the cognitive processes needed for academic success [21,22].

Previous studies have reported positive associations between sleep and academic performance, as well as memory. A review of studies that evaluated the association between sleep and memory in children and adolescents reported that sleep is associated with improved working memory and memory consolidation in children and adolescents [23]. Another study with three separate meta-analyses indicated associations between sleep quality, sleep duration, sleepiness, and school performance in children and adolescents, with younger participants demonstrating a larger effect size [24]. In these

Abbreviations: SES, Socioeconomic status; GS, Good sleep; PS, Poor sleep; SD, Standard deviation; M, Mean.

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meta-analyses, sleepiness showed the strongest association with school performance, followed by sleep quality and sleep duration.

However, previous studies examining the associations between academic performance and sleep in school-aged children have suffered from multiple limitations that bar us from clearly determining the nature and strength of associations between sleep duration/quality and the report-card grades of typically developing healthy elementary-school-aged children. The limitations are in the following domains.

Academic Outcome Measures. A large proportion of the studies [15,25–35] conducted to examine the association between sleep and academic performance did not use report-card grades but used indirect measures of academic performance such as performance on standardized tests that measure ability or neurocognitive batteries that measure cognitive skills associated with academic performance [26–28,33]. This does not indicate how this translates to grades – that is, to the measures by which academic performance is being measured.

Other studies [13,25,34,35] have used teachers' reports on scales associated with achievement but do not measure it directly and are not specific to academic subjects. This makes it impossible to assess accurately the association between the actual performance in school and sleep, and it does not allow for any conclusion regarding potential differential associations between sleep and specific subjects to be drawn.

Of the studies that included information related to report-card grades [15,30,31,36–40], all but two [36,38] used general proxies of performance rather than the actual grades; that is, they asked for general descriptions of overall performance. Such nonspecific information does not allow to precisely determine the nature of the associations between sleep and report-card grades. In addition, these studies lumped different subjects together, even though sleep might not affect all subjects similarly. It is important to determine which aspects of academic performance are specifically affected by short or poor sleep because sleep interventions may then be developed to improve these domains.

Sleep Measures Used. To date, only two studies [36,38] have examined the associations between sleep and actual report-card grades of typically developing elementary school students. However, these studies used subjective measures of sleep.

Using these kinds of measures is another problem that has limited the usefulness of the previous studies: with four exceptions [13,27,28,33], all of the studies that examined sleep and academic performance in typically developing school-aged children used subjective sleep measures, such as sleep logs [15,37], sleep questionnaires [15,25,26,29,31,32,34–38,40], interviews [39], or surveys [30]. These measures do not allow for the retrieval of objective documentation of either sleep duration or sleep quality – the two aspects of sleep that are believed to affect academic performance – although Mayes et al. [28] found no significant associations between sleep and academic performance.

The four studies that used objective sleep measures either did not use report-card grades to measure academic performance [13,28,33] or focused on students with sleep disruption rather than on typically developing children [27], so their findings do not apply to the larger cohort of typically developing students.

Population Studied. The only study that used objective sleep measures and actual report-card grades focused on students with sleep disturbances [41]. This is a general problem in the field: a large proportion of the studies examining sleep and academic performance have focused on children with reported sleep disturbances [42]. Unfortunately, clinical sleep disorders (e.g., sleep apnea) can be associated with cognitive deficits that may affect academic performance. Therefore, such studies do not allow to draw meaningful conclusions regarding the associations between sleep and academic performance in the larger cohort of typically developing children who do not suffer from a sleep disorder [42].

With the exception of four studies [34,43–45], most of the existing studies failed to control for socioeconomic status (SES) [13,15,25,26,28–31,33,35–40]. Buckhalt et al. [44] found that SES and ethnicity moderated the relation between sleep and cognitive performance, where more optimal sleep protected against cognitive performance difficulties. The same moderation effect was found 2 years later in a follow-up study [45]. Bub et al. [43] also reported race/ethnicity to be a significant moderator of the link between sleep and cognitive performance, with Sleepiness serving as a vulnerability factor for poor cognitive outcomes, especially among African-American children. Similarly, Li et al. [34] reported that sleep behaviors were linked to SES differences (such as parental education). Consequently, failing to control for SES might bias the results, adding to the limitations of previous studies.

Finally, several of the previous studies analyzed data from school-aged children and adolescents together [15,26,29–33,35,36]. This is an issue because sleep needs, sleep patterns, and executive functions all show significant changes in adolescence. In addition, mixing the two age groups could have led to the loss of important information that is unique to younger children, whose developing cognitive systems may be more susceptible to the impacts of sleep.

The goal of the present study was to examine the associations between the objective measures of sleep duration and sleep efficiency with the actual report-card grades that healthy typically developing school-aged children obtained in math, languages, science, and art, while controlling for the potential confounding effects of SES, age, and gender. Our questions were as follows: 1) Of the academic subjects taught in elementary school (math, languages, science, and arts), is performance specifically associated with sleep and, if so, among which subject(s)? 2) What aspects of sleep are relevant to academic performance, as indicated by report-card grades? 3) To what extent is sleep associated with each subject, that is, how much of the variance in predicting the subjects' grades could be explained by sleep efficiency or sleep duration?

1.1. Hypotheses

1) Based on the important role sleep plays in learning and memory [23,46], we hypothesized that sleep will be significantly associated with academic performance in all of the subjects taught in elementary school. 2) Based on the previous findings reviewed by Dewald et al. [24], we hypothesized that sleep efficiency will contribute more than sleep duration to explain the variances in the prediction of report-card grades. 3) Given the role of executive functions in math and languages, and studies showing that sleep disruption and deprivation negatively impact executive functions [11,21], we hypothesized that the degrees of variance explained by sleep will be larger for the subjects of math and languages.

2. Method

2.1. Participants

The sample consisted of 75 participants: 41 boys and 34 girls aged 7–11 years (mean = 8.85, standard deviation (SD) = 1.6) who were enrolled in Cycle 1 (Grades 1 and 2, $N = 23$), Cycle 2 (Grades 3 and 4, $N = 26$), and Cycle 3 (Grades 5 and 6, $N = 26$). A participant was excluded from the study if he or she had: 1) a history of psychiatric illness, developmental disorder, learning disability, or psychosis that might affect academic performance; 2) any medical or psychiatric condition (e.g., depression or anxiety) that might interfere with sleep; and/or 3) was taking any medication that might interfere with sleep. Based on these criteria, seven children were excluded from participation (four with anxiety, one with

attention-deficit hyperactivity disorder (ADHD), one with dyslexia, and one with trauma).

The participants were recruited from three elementary schools of the Riverside School Board, which governs the public education of the English-speaking population of Montreal's south shore. These schools use the same educational curricula, apply the same grading systems, and work under the same educational requirements of the Ministry of Education. The students in these schools come predominantly from families of the middle socioeconomic class. Parents responded to flyers sent home by teachers in each classroom. The study was approved by the Research Ethics Board at the Douglas Mental Health University Institute (Montreal, Canada) and the Research Ethics Board of the Riverside School Board. Informed consent was obtained from the parents of all participants.

Most of the participants were Caucasian (63.8%), with the remainder classified as Mixed Ethnicity (18.1%), Asian (13.9%), Hispanic (2.8%), and African–American (1.4%). All participants spoke English as their first language. The majority of children (82.6%) came from families in which the parents were married, 8.9% came from families in which the parents were separated or divorced, and 8.5% came from families with a single mother. In terms of education, 36.8% of the mothers and 30.4% of the fathers had university-level educations, 39.7% of the mothers and 31.3% of the fathers had college-level educations, and 23.5% of the mothers and 38.3% of the fathers had high school educations. Regarding income, 10.3% of the households had annual combined incomes <$25,000, 17.6% had annual incomes of $25,000–$45,000, 22% had annual incomes of $45,000–$65,000, 20.6% had annual incomes of $65,000–$95,000, and 29.5% had annual incomes >$95,000.

2.2. Procedures

Prior to enrollment, eligibility was determined by screening for the absence of sleep disorders, health problems, and behavioral problems, based on the parents' responses to a detailed questionnaire regarding the health of their child. Each participant's sleep pattern was assessed in the home environment using a miniature actigraph (AW-64 series; Mini-Mitter, Sunriver, OR, USA). An actigraph was delivered to the child's home, and parents were instructed to attach it to the child's nondominant wrist at bedtime for five consecutive nights (Monday through Friday). They were asked to keep a diary of their child's daily bedtime and wake time (sleep log) during the same period. Sleep was monitored on weeknights during the regular academic year, excluding school holidays. In addition, the parents were asked to provide the child's most recent report card.

2.3. Measures

2.3.1. Actigraphy

Nighttime sleep was monitored by actigraphy, which uses a wristwatch-like device (AW-64 series, Mini-Mitter, Sunriver, OR, USA) to evaluate sleep by measuring movement. One-minute epochs were used to record actigraphic sleep data, and the Actiware Sleep 3.4 software (Mini-Mitter, Sunriver, OR, USA) was used to score sleep. Actigraphy has been shown to be a reliable method for evaluating sleep in the studied age group [47], and the Actiware Sleep software was previously validated and shown to have a high correspondence with polysomnographic measures [47–50]. The total sum of activity counts was computed for each 1-min epoch. If the sum exceeded a threshold sensitivity value of the mean score during the active period /45, then the epoch was considered waking. Otherwise, the epoch was considered sleep. The reported bedtime and wake time (provided by sleep logs) were used as the start and end times for the analyses and were set by the researcher based on the sleep log and the actigraphy data. Sleep onset and sleep end were calculated by the software. The utilized indices were sleep duration and sleep efficiency. Sleep duration is the sum of epochs between sleep onset and sleep end that are scored as "sleep" according to the algorithm. Sleep efficiency is the percentage of time in bed spent sleeping. These measures were averaged over the five nights, allowing us to examine the children's habitual sleep patterns.

2.3.2. Daily sleep logs

Bedtimes and wake times were taken from sleep logs that were maintained by the parents.

2.4. Academic performance

Parents were asked to provide a copy of their child's end-of-year report card. Grades were given on a scale between 0 and 100 for the following subjects: English language, French as a second language, mathematics, science and technology, and art. Students in Cycle 1 (Grades 1 and 2) did not have grades in science and technology.

2.5. Socioeconomic status

Information regarding education, marital status, and household income was collected through a background questionnaire. Two different markers were used to determine SES: combined annual family income and maternal education. *Household income* was taken as the sum of the annual income from all sources received by all members of the household. This measure was selected based on the recommendation of Daly et al. [51], whose empirical examination of links between SES and health in prospective data from a nationally representative survey suggested that the economic components of SES should be a standard feature when monitoring links between SES and health. Parental education was examined because strong links have been found between parents' educational attainment and their children's achievements in school [52–55].

A principal component analysis (employing Varimax rotation) was used to aggregate these measures into a reliable index of familial SES. This analysis produced a one-factor solution that accounted for 77.3% of the variance (eigenvalue, 1.55) and was weighted by household income and maternal education (factor loadings, 0.88 and 0.87, respectively). It was therefore termed SES.

Health information was collected using a detailed questionnaire that asked parents for specific information about the child's medical condition, psychological condition, any diagnoses in the present or past, lengths of any illness, and the use of any treatments or medications.

2.6. Data analysis

Descriptive statistics were computed for all relevant variables. To examine differences in the sleep variables among students of the different elementary school cycles and between genders, two-way analyses of variance (ANOVAs) were performed on the sleep measures with Cycle ((Cycle 1 (Grades 1 and 2), Cycle 2 (Grades 3 and 4), and Cycle 3 (Grades 5 and 6)) and Gender as the independent variables. Scheffé's post hoc tests were conducted to identify the sources of the differences.

Because age, gender, and SES have been shown to affect sleep [20,44,56,57] and academic performance [58,59], we examined the associations of these parameters with sleep duration, sleep efficiency, and report-card grades using Pearson product-moment correlations.

To examine whether the sleep variables were associated with report-card grades, the relationships between actigraphic measures of sleep duration/efficiency and report-card grades were tested

using hierarchical regression analyses adjusted for the potential confounders of age, gender, and SES. Before the hierarchical multiple regression analyses were performed, the independent variables were examined for collinearity. The variables found to explain the report-card grades were entered in two steps. In Step 1, the report-card mark in each specific subject was the dependent variable, and age, SES, and gender were the independent variables. In Step 2, the actigraphic measures of sleep efficiency and sleep duration were entered. For each of the outcome variables, the two blocks were evaluated sequentially. Step 1 evaluated only Block 1, and Step 2 evaluated only Block 2 controlled for Block 1. A statistical test of the change in R^2 from Stage 1 was used to evaluate the importance of the variables entered in Stage 2.

Based on the findings from the regression analyses showing that sleep efficiency was associated with report-card grades, we wanted to examine the differences between students with high and low sleep efficiency in the grades that were found to be significantly associated with sleep efficiency. In order to do that, participants were divided into two groups based on the mean (M) sleep efficiency score, with participants above and below the mean (M = 79.96%) placed in the Poor Sleep (PS) group (Minimum = 70.27, Maximum = 79.91) and Good Sleep (GS) group (Minimum = 80.02, Maximum = 93.23), respectively.

To determine whether there were significant differences in the report-card grades in math, English language, and French as a second language of students in the GS and PS groups, we performed multivariate analyses of covariance (MANCOVAs) with the sleep group (PS or GS) taken as the between-subject independent factor, the report-card grades taken as the dependent variables, and SES taken as a covariate. We utilized MANCOVAs to reduce the probability of Type I errors.

When such differences were found, we examined whether they were similar to those previously observed between the control group and the groups that received early educational interventions aimed at improving cognition/academic performance [60]. We suggest that, all other things being equal, this should show us what could potentially be achieved if we improved the sleep efficiency of the poor sleepers to match that of the good sleepers.

We followed the approach suggested by Barnett [61], who reviewed the effectiveness of early educational interventions. According to Barnett, to ensure comparability across studies, the effects should be reported as fractions of SDs, calculated as the difference between the treatment and control groups divided by the SD of the control group. We therefore calculated the difference between the GS and PS groups and divided it by the SD of the PS group. The abovementioned study found an average of 0.35 SD for improvements in cognition [61]. We therefore tested whether the differences calculated in the present study were ≥0.35 SD.

All analyses employed SPSS Version 20.0 for Windows (IBM Corporation, Armonk, NY, USA), and $p < 0.05$ was taken as indicating statistical significance.

3. Results

3.1. Sleep duration and efficiency

The means and SD of the demographic, sleep, and academic performance characteristics of the study participants are presented in Table 1. The parentally completed sleep logs indicated that the participants, on average, spent 601 min (SD 43 min) in bed per night. The mean reported bedtime was 20:44 (SD 41 min), and the mean reported rising time was 6:43 (SD 29 min). The time spent in bed, as measured by actigraphy, was 573.41 min (SD 39.19 min); this was an average of 28.4 min less than the parental reports. The mean sleep efficiency score was 80% (SD 7.9).

Table 1
Descriptives by Cycle and Gender of Sleep Variables and Report Card Marks (N = 68).

Variable	All Cycles						Cycle 1 (N = 23)						Cycle 2 (N = 23)						Cycle 3 (N = 22)					
	Total		Males		Females		Total		Males		Females		Total		Males		Females		Total		Males		Females	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Sleep																								
Actigraphy																								
Sleep duration (min)	573.41	39.19	567.99	38.29	577.96	39.88	606.02	30.20	597.60	25.90	612.50	32.63	564.26	27.35	560.43	23.60	567.20	30.53	548.90	35.71	547.95	43.79	549.84	27.55
Sleep efficiency (%)	79.82	7.88	79.66	7.42	79.95	8.35	77.87	11.55	77.99	11.80	77.78	11.83	79.72	5.78	80.66	4.22	78.99	6.82	81.97	3.80	80.28	4.42	83.66	2.15
Sleep log																								
Bed time	20:44	0:41	20:44	0:38	20:44	0:45	20:21	0:40	20:25	0:41	20:25	0:40	20:39	0:32	20:40	0:39	20:38	0:28	21:12	0:36	21:05	0:25	21:19	0:45
Wake-up time	6:43	0:29	6:42	0:24	6:45	0:32	6:55	0:37	6:45	0:30	7:04	0:42	6:40	0:19	6:41	0:21	6:40	0:19	6:34	0:24	6:39	0:22	6:29	0:25
Report card marks (%)																								
Math	75.13	12.44	73.63	11.22	76.35	13.38	74.50	13.46	77.56	8.55	72.38	16.02	78.61	9.41	78.00	8.29	79.08	10.50	72.14	13.76	66.45	12.45	77.82	13.11
English language	75.63	10.62	72.81	10.07	78.00	10.62	74.26	13.15	72.10	13.18	75.92	13.41	77.96	8.30	77.40	7.57	78.38	9.10	74.64	9.88	69.27	7.81	80.00	8.99
French as a second language	75.45	14.26	70.13	16.73	79.76	10.23	79.82	12.16	77.67	12.52	81.31	12.19	76.22	11.72	72.00	15.41	79.46	6.89	70.27	17.29	62.27	18.72	78.27	11.67
Science and technology[a]	77.01	10.48	73.05	11.15	80.48	8.68	–	–	–	–	–	–	80.28	6.62	79.05	6.45	81.23	6.85	73.59	12.66	67.59	11.93	79.59	10.74
Art	78.71	7.70	75.13	7.79	81.70	6.30	78.67	8.20	76.50	8.59	80.35	7.80	80.28	5.95	77.45	5.44	82.46	5.55	77.09	8.74	71.77	8.32	82.41	5.39

Abbreviations: M = mean; SD = standard deviation.
[a] n = 45; only Cycle 2 and Cycle 3 students have science and technology.

3.2. Differences in sleep variables between students of different genders and elementary school cycles

3.2.1. Sleep duration

Two-way ANOVAs yielded a main effect for Cycle ($F_{(2,69)} = 24.65$, $p < 0.0001$). Post hoc analyses using Scheffé's post hoc criterion for significance showed that the sleep duration was significantly longer in Cycle 1 (Grades 1 and 2) compared to the other cycles, indicating that the younger children slept longer. There was no statistically significant difference between Cycle 2 (Grades 3 and 4) and Cycle 3 (Grades 5 and 6). Children in Cycle 1 slept an average of 606.02 min (SD 30.20), while those in Cycle 2 slept an average of 564.26 min (SD 27.35) and those in Cycle 3 slept an average of 548.90 min (SD 35.71). The main effect for Gender was not significant.

3.2.2. Sleep efficiency

The main effect for Cycle or Gender was not significant. Sleep efficiency was relatively stable across Cycle 1 (78%, SD 11.55), Cycle 2 (80%, SD 5.78), and Cycle 3 (82%, SD 3.80).

3.3. Relations between sleep efficiency, sleep duration, and report-card grades

3.3.1. Correlations between variables

The correlations between actigraphic sleep measures, report-card grades, age, and SES are presented in Table 2. When we examined the associations between a child's age and variables reflecting sleep and academic performance, we found that older age was associated with decreased sleep duration and poorer performance in French as a second language. A higher SES score was associated with better grades in math, French as a second language, and art. The SES status was not related to sleep duration or sleep efficiency.

3.3.2. Regression analyses

To examine whether sleep duration or sleep efficiency (as measured by actigraphy) contributed to report-card grades, we performed hierarchical multiple regression analyses. The unstandardized regression coefficients (B), intercepts, and standardized regression coefficients (β) for the full models are reported in Table 3. The results of the variance inflation factors (all <2.0) and collinearity tolerances (all >0.76) suggest that the estimated βs were well established in the regression model. The results, broken down by subject, are as follows.

3.3.3. Math

The results of Step 1 indicated that the variance (R^2) accounted for by the first three independent variables (Age, Gender, and SES) equaled 0.10 (adjusted $R^2 = 0.06$), which was not significantly different from zero ($F_{(3,63)} = 2.3$, $p < 0.08$). SES was the only statistically significant independent variable ($\beta = 0.29$, $p < 0.05$). In Step 2, the two actigraphic sleep measures were entered into the regression equation. The change in variance (ΔR^2) accounted for by these measures was 0.14, which was significantly different from zero ($F_{(3,63)} = 3.07$, $p < 0.005$). In this step, we found that sleep efficiency contributed significantly to explaining report-card grades in math ($\beta = 0.28$, $p < 0.05$).

3.3.4. English language

In Step 1, the R^2 for Age, Gender, and SES equaled 0.10 (adjusted $R^2 = 0.06$), which was not significantly different from zero ($F_{(3,63)} = 2.3$, $p < 0.08$). Gender was the only statistically significant independent variable ($\beta = -0.25$, $p < 0.05$). In Step 2, ΔR^2 was 0.09, which was significantly different from zero ($F_{(3,63)} = 3.33$, $p < 0.05$). In this step, we found that sleep efficiency contributed significantly to explaining report-card grades in English language ($\beta = 0.28$, $p < 0.05$).

3.3.5. French as a second language

In Step 1, the R^2 for Age, Gender, and SES equaled 0.30 (adjusted $R^2 = 0.27$), which was significantly different from zero ($F_{(3,63)} = 9.17$, $p < 0.000$). Age, Gender, and SES were all statistically significant ($\beta = -0.25$, $p < 0.05$; $\beta = -0.32$, $p < 0.003$; and $\beta = 0.34$, $p < 0.002$, respectively). In Step 2, ΔR^2 was 0.07, which was significantly different from zero ($F_{(3,63)} = 3.28$, $p < 0.05$). In this step, we found that sleep efficiency contributed significantly to explaining report-card grades in French as a second language ($\beta = 0.27$, $p < 0.05$).

3.3.6. Science

In Step 1, the R^2 for Age, Gender, and SES equaled 0.24 (adjusted $R^2 = 0.19$), which was significantly different from zero ($F_{(3,41)} = 4.33$, $p < 0.02$). Gender was the only statistically significant independent variable ($\beta = -0.36$, $p < 0.02$). In Step 2, ΔR^2 was 0.04, which was not significantly different from zero ($F_{(3,41)} = 0.97$, $p > 0.05$). In this step, sleep did not contribute significantly to explaining report-card grades in science.

3.3.7. Art

In Step 1, the R^2 for Age, Gender, and SES equaled 0.30 (adjusted $R^2 = 0.27$), which was significantly different from zero

Table 2
Intercorrelations of Age, SES, Actigraphy Variables, and Report-Card Marks ($N = 68$).

Variable	Pearson r							
	2	3	4	5	6	7	8	9
1. Child's age	0.05	−0.60***	0.18	−0.08	0.04	−0.30*	−0.20	−0.13
2. SES	–	−0.04	−0.00	0.29*	0.19	0.35**	0.27	0.34**
Actigraphy								
3. Sleep duration	–	–	−0.23*	−0.15	−0.10	−0.17	0.03	0.11
4. Sleep efficiency	–	–	–	0.30*	0.29*	0.22	0.11	0.07
Report card marks								
5. Math	–	–	–	–	0.78***	0.38**	0.77***	0.57***
6. English language	–	–	–	–	–	0.41**	0.78***	0.55***
7. French as a second language	–	–	–	–	–	–	0.50***	0.34**
8. Science and technology	–	–	–	–	–	–	–	0.69***
9. Art	–	–	–	–	–	–	–	–

Abbreviation: SES = socioeconomic status.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Table 3
Summary of Hierarchical Regression Analysis Predicting Report-Card Marks ($N = 68$).

Covariates and Predictors	Math	English language	French as a second language	Science and technology[a]	Art	Covariates and Predictors	Math	English language	French as a second language	Science and technology[a]	Art	Covariates and Predictors	Math	English language	French as a second language
	B		*β*	*B*			*B*		*β*	*B*			*B*		*β*
Step 1: Covariates															
Child's age	−0.42		−0.06	0.37		0.06	−2.16		−0.25*	−1.70		−0.19	−0.44		−0.09
Child's gender	−2.70		−0.11	−5.20		−0.25*	−9.18		−0.32**	−7.36		−0.36*	−6.41		−0.42***
SES	3.6		0.29*	2.00		0.19	4.94		0.34**	2.08		0.21	2.52		0.33**
R^2 for Step 1		0.10			0.10			0.30***			0.24*			0.30***	
Step 2: Predictors															
Sleep duration	−0.08		−0.27	−0.03		−0.10	0.00		0.01	−0.03		−0.09	0.00		0.01
Sleep efficiency	0.43		0.28*	0.37		0.28*	0.48		0.27*	0.34		0.17	0.08		0.08
ΔR^2 for Step 2		0.14**			0.09*			0.07*			0.04			0.01	

Abbreviation: SES = socioeconomic status.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
[a] $n = 45$; only Cycle 2 and Cycle 3 students have science and technology.

Table 4
Descriptives by Sleep Efficiency Level of Report-Card Marks ($N = 68$).

Subject	PS Group ($N = 25$)		GS Group ($N = 43$)	
	M	SD	*M*	SD
Math	71.04	13.69	77.57	11.10
English language	72.00	11.47	77.44	9.61
French as a second language	71.04	13.82	78.07	14.03

Abbreviations: PS = poor sleep; GS = good sleep; M = mean; SD = standard deviation.

($F_{(3,63)} = 9.54$, $p < 0.000$). Gender and SES were statistically significant ($\beta = -0.42$, $p < 0.000$; and $\beta = 0.33$, $p < 0.003$; respectively). In Step 2, ΔR^2 was 0.006, which was not significantly different from zero ($F_{(3,63)} = 0.28$, $p > 0.05$). In this step, sleep did not contribute significantly to explaining report-card grades in Art.

3.4. Comparisons of report-card grades between PS and GS groups

In Table 4, we present the means and the SDs of the report-card grades in math, English language, and French as a second language, divided into groups according to their sleep efficiency level. When we compared the grades of children in the PS group versus those in the GS group while controlling for SES, MANCOVA revealed a significant difference ($F_{(3,62)} = 3.22$, $p < 0.05$), indicating that the grades of children in the GS group were better than the grades of children in the PS group. Post hoc univariate analysis revealed significant differences in math ($F_{(1,64)} = 6.05$, $p < 0.01$), English language ($F_{(1,64)} = 6.33$, $p < 0.02$), and French as a second language ($F_{(1,64)} = 5.88$, $p < 0.07$).

Using Barnett's formula, the effects found were 0.48 SD for math, 0.52 SD for English language, and 0.51 SD for French as a second language.

4. Discussion

The present study examined the associations between two objectively measured aspects of sleep (sleep duration and sleep efficiency) and the subject-specific report-card grades of healthy school-aged children, while controlling for confounders known to relate to academic performance [54,62]. Our main findings were as follows: 1) grades in math, English language, and French as a second language were significantly associated with sleep, whereas grades in science and art were not; 2) sleep efficiency (but not sleep duration) was associated with report-card grades in these subjects; 3) the addition of sleep efficiency to the models significantly increased the explained variance above and beyond Gender, Age, and SES for math (by 14%), English language (by 9%), and French as a second language (by 8%); and 4) the differences between students with poor and good sleep efficiency in math, English language, and French as a second language were higher than those previously obtained for cognitive outcomes in intervention programs aimed at improving the academic success of young children [60].

Consistent with our hypothesis, sleep efficiency was significantly associated with grades in math, English language, and French as a second language. Multiple studies have shown that sleep loss impairs the performance of the supervisory control system in adults [63–65], which is associated with success in mathematics. Another key component of success in mathematics is the ability to understand highly logical and systematic relationships among numerals and the procedures that can be used to operate on them [66]. Previous studies examining the associations between sleep and cognitive functioning have mostly been conducted with adults, and have indicated that sleep is specifically related to the capacities to think

logically, solve problems in novel situations, identify patterns and relationships, and perform complex tasks that require abstract thinking [11,63–65]. We propose that future studies should further examine whether the associations between sleep and performance in mathematics could be related to the impact of sleep on the above-described skills, which underlie mathematical performance and are strongly associated with executive functions. Sleep efficiency was also related to children's grades in languages. Experimental studies examining the association between sleep and language have shown that sleep loss impairs both short and novel language tasks [67], and that sleep is critical to the acquisition of novel language by infants [68]. Executive processing has been proposed to play a key role in language learning among children [69], and sleep deprivation has been shown to significantly affect these processes. Hence, future studies should examine if sleep is specifically related to the use and development of language.

These findings are consistent with those from other studies examining the association between sleep efficiency or sleep disorders and academic performance. Poor performance in math and language (Portuguese), but not in other subjects, was found in children with reported symptoms of sleep disorders (SSDs) and reported symptoms of sleep-breathing disorders (SSBDs) in a large study conducted in 5400 children in Brazil [40]. Children with SSDs (and particularly SSBDs) were at an increased risk of poor academic performance in math and Portuguese, as assessed by their grades, which were reported on a scale of 0–10. Interestingly, another study that examined the amount and quality of children's sleep as a moderator of the relationship between parental attachment and the child's academic functioning on a standardized group-administered achievement test (the Stanford Achievement Tests) found that attachment insecurity was associated with lower achievement in math for children with objective sleep problems (lower quantity and efficiency) [27]. A Turkish study that used questionnaires to assess students' sleep in relation to their grades found an association between sleep time and success in Turkish language studies [70]. Collectively, our present findings are consistent with those of other studies that used reported sleep measures, reported grades, standardized test results, and objective measures of sleep across different cultures and countries (e.g., USA, Canada, Turkey, and Brazil).

Math and reading are the most powerful predictors of later learning and academic success [71]. An early knowledge of mathematics has been shown to predict later school success in elementary [72] and even high school [73–75], and also appears to predict later reading achievement even better than early reading skills [72]. Our results showing that sleep is associated with math and language performance (which is closely related to reading) therefore suggest that sleep is associated with the academic subjects that are highly predictive of overall academic success.

Contrary to our hypothesis, we found that sleep duration was not associated with report-card grades. This, however, is consistent with earlier studies using subjective measures of sleep and proxy measures of grade point averages (GPAs) [2,24,76–82], which found that sleep duration had inconsistent effects on these measures and that the association between sleep duration and school performance was significantly smaller than that between sleep quality and school performance. One possible explanation for this is that there are significant individual differences in sleep needs and vulnerabilities to sleep deprivation (i.e., the magnitude of performance impairment given a fixed amount of sleep reduction) [83]. As these individual differences are difficult to measure, and thus cannot be controlled for, they could affect the impact of sleep duration on academic performance. For example, performance under sleep deprivation may be "protected" among children who need less sleep to function or who are more resistant to the impacts of sleep deprivation. Future studies should aim to differentiate between long and short sleepers and examine how their performances might be differentially affected by poor sleep and sleep deprivation, and to investigate individual differences more thoroughly.

4.1. Practical implications and future directions

We observed that the sleep duration declined with increased age. Given this trend, we suggest that prevention strategies aimed at reducing the prevalence of insufficient sleep quality or quantity should be initiated during the elementary school years. In addition, we suggest that sleep screenings should be conducted on a regular basis among school-aged children, to ensure proper intervention when a child suffers from an undiagnosed or unnoticed sleep problem. This is particularly important for students who exhibit difficulties in mathematics, languages, or reading.

Two meta-analyses have examined the impact of educational interventions aimed at improving academic performance or school readiness. One included 123 quasi-experimental and experimental studies of U.S. center-based educational interventions [84], while the other reviewed 30 studies of non-U.S. early educational programs, mostly in low-income countries [85]. The U.S. meta-analysis found average effects of 0.23 SD for cognition. The international meta-analysis only examined the results from relatively rigorous studies and found average effects for early educational interventions of 0.35 SD for cognition. In the present study, we did not change sleep efficiency or evaluate an intervention study. However, to estimate what we might expect to see if we improved the sleep efficiency of the studied students, we examined the differences in the report-card grades of students in the GS group and the PS group while controlling for SES. We used the approach taken by Barnett [61] when examining the impact of educational interventions to the differences in report-card grades between good and poor sleepers. We suggest that, all other things being equal, this should show us what could potentially be achieved if we improved the sleep efficiency of the poor sleepers to match that of the good sleepers. The difference between the PS and GS groups in math, English language, and French as a second language were all higher than those obtained for cognition among the effective interventions included in the meta-analyses.

When combined with previous reports demonstrating that small changes in sleep can affect the cognitive processes associated with academic performance [86–88], the findings of the present study provide a rationale to ask the following: If children sleep better, do they perform better in school? A trial is needed to determine whether systematically improving and extending sleep at school entry improves learning outcomes during the early years of formal schooling. Although the findings of the present study do not directly answer this question, they lay a foundation for further examinations of this possibility. Sleep improvement has the potential to yield large gains in learning and development with little financial burden.

Another practical consideration is the need to tailor future interventions to individual differences/factors that can affect the interplay between sleep and academic performance. One such factor is SES. Consistent with previous reports [44,89], we found that SES was significantly associated with performance on some academic subjects (e.g., math, French as a second language, and art). Future studies should seek to determine which specific aspects of SES form the basis for its impact on the interplay between sleep and academic performance, as this could inform the development of new interventions aimed at improving sleep as a means to improve academic success. To properly tailor such interventions, it will be essential for researchers to identify and address any potential barriers (e.g., the physical sleep environment and/or parents' schedules) or facilitators (e.g., coping strategies) [90]. This should help maximize the potential benefit of interventions that may help reduce health disparities in an important health domain.

4.2. Limitations

The present study had several limitations. First, although we excluded children with known sleep disorders or other medical conditions, some may have had undiagnosed medical problems or sleep disorders that could have affected their sleep efficiency or duration. Second, our findings are correlational, meaning that cause-and-effect connections cannot be determined. Third, although our statistical power analysis indicated that the utilized sample size was sufficient to detect significant effects, our sample was relatively small and should optimally be increased. Thus, we suggest that our results should be considered preliminary. Finally, although the identified associations are consistent with and extend the findings of previous studies showing associations between sleep and cognitive outcomes, the underlying mechanisms are still poorly understood. Future work in educational neuroscience could help identify the mechanisms responsible for the associations between sleep and critical academic skills.

5. Conclusions

This study used report-card grades as the outcome measures and examined their associations with objective measures of sleep. Our findings suggest that higher sleep efficiency in healthy school-aged children is positively associated with better grades in math, English language, and French as a second language. Consistent with previous studies, the effects were small but significant. These findings add to our understanding of the interplay between sleep and academic performance in typically developing children, and have important practical implications. The significant associations between sleep efficiency and grades in academic subjects associated with present and future academic success emphasize that it is important to prioritize sleep and proactively screen, diagnose, and treat sleep problems in school-aged children. Our findings further suggest that strategies aimed at improving sleep efficiency should be integrated into programs for improving the school readiness of children in math and languages, as this could represent an innovative and cost-effective approach for improving the outcomes of such programs.

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Conflict of interest

The authors have no conflict of interest relevant to this article to disclose.

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